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CONTENTS

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THE LATEST TRIASSIC AND EARLY JURASSIC FORMATIONS OF THE NEWARK BASIN (EASTERN NORTH AMERICA, NEWARK SUPERGROUP): STRATIGRAPHY, STRUCTURE, AND CORRELATION

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ABSTRACT. *Newark Supergroup deposits of the Newark Basin (New York, New Jersey, and Pennsylvania) are here divided into nine formations called (from the bottom up): Stockton Formation (maximum 1800 m); Lockatong Formation (maximum 1150 m); Passaic Formation (maximum 6000 m); Orange Mountain Basalt (maximum 200 m); Feltville Formation (maximum 600 m); Preakness Basalt (maximum +300 m); Towaco Formation (maximum 340 m); Hook Mountain Basalt (maximum 110 m); and Boonton Formation (maximum +500 m). The latter seven formations are new and result from subdividing the Brunswick Formation and Watchung Basalt of Kümmel and Darton. Each formation is characterized by its own suite of lithologies, the differences being especially obvious in the number, thickness, and nature of their gray and black sedimentary cycles (or lack thereof).*

Newark Basin structure still escapes comprehensive understanding, although it is clear that faults (predominantly normal) and onlaps bound both the eastern and western edges of the basin. The cumulative thickness of formations and the apparent movement of the faults is greater on the western than the eastern side, however.

Fossils are abundant in the sedimentary formations of the Newark Basin and provide a means of correlating the sequence with other early Mesozoic areas. The Stockton, Lockatong, and most of the Passaic Formation are Late Triassic (?Middle and Late Carnian — Rhaetic) while the uppermost Passaic Formation (at least locally) and younger beds appear to be Early Jurassic (Hettangian and Sinemurian) in age. The distribution of kinds of fossils is intimately related to sequences of lithologies in sedimentary cycles.

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INTRODUCTION

Despite well over a century of interest in the early Mesozoic Newark Supergroup of eastern North America, many fundamental aspects of its historical and structural geology remain unexplored. In part, this is due to the complexity of stratigraphic and structural relations in the individual basins, coupled with the rarity of continuous exposures. As a result, much of our accepted understanding of the Newark Supergroup has been based on incomplete observations and opinion. The purpose of this paper is to provide a more thorough observational foundation against which past hypotheses may be assessed and on which future work may be based. Emphasis is placed on the younger beds of the Newark Basin, for they have never been examined in detail, and a new stratigraphic framework is proposed. These younger Newark Basin beds provide us with a key to understanding the entire basin column, which in turn is crucial to the context in which early Mesozoic organic evolution, continental sedimentation, and tectonic development are to be studied.

REGIONAL SETTING

Triassic and Jurassic Newark Supergroup rocks (Figure 1) (Olsen, 1978; Van Houten, 1977) occupy numerous elongate basins in eastern North America and consist of predominantly detrital fill locally more than 10,000 m thick. In most

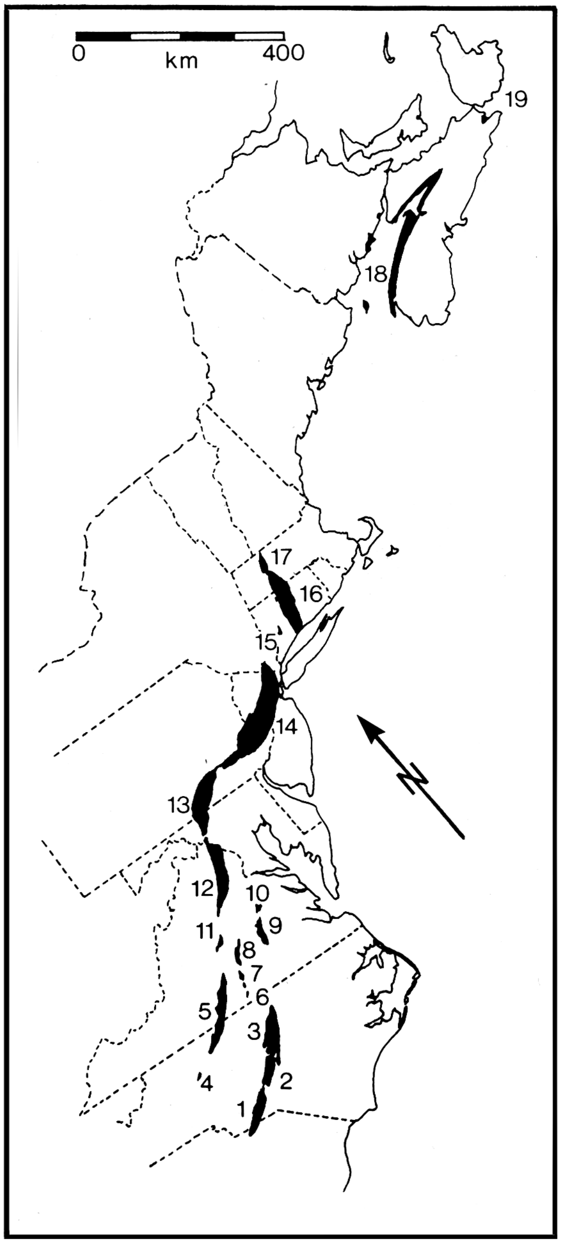

FIG. 1. Newark Supergroup deposits exposed in eastern North America: 1, Wadesboro Basin of Chatham Group; 2, Sanford Basin of Chatham Group; 3, Durham Basin of Chatham Group; 4, Davie County Basin; 5, Dan River — Danville Basins of Dan River Group; 6, Scottsburg Basin; 7, Basins south of the Farmville Basin; 8, Farmville Basin. 9, Richmond Basin; 10, Taylorsville Basin; 11, Scotsville Basin; 12, Culpeper Basin (Culpeper Group; 13, Gettysburg Basin; 14, Newark Basin; 15, Pomperaug Basin; 16, Hartford Basin; 17, Deerfield Basin; 18, Fundy Basin (Fundy Group); 19, Chedabucto Basin (= Orpheus Graben?). Data primarily from Calver, 1963, King, *et al.*, 1944; Van Houten, 1977; and Olsen, 1978.

areas, red clastics are the dominant sedimentary rocks and tholeiitic, intrusive and extrusive diabases and basalts are the most common volcanics. These unconformably overlie (or rarely intrude) Precambrian and Palaeozoic rocks and are overlain by post-Jurassic rocks of the Coastal Plain, or alluvium and soils.

The Newark Basin is the most northerly of three Newark Supergroup basins lying in an arcuate belt stretching from southern New York to central Virginia (Figure 2). The region has attracted the attention of researchers since the beginnings of North American geological work (Kalm, 1753-1761; Schopf, 1783-1784); by about 1890 the deposit had been mapped out (Lyman, 1895; Cook, 1868) and by 1900 the currently used rock-stratigraphic framework was established (Table 1). Kümmel (1897) divided the Newark Basin sequence into three formations: the Stockton, Lockatong, and Brunswick. As recognized by Kümmel, the Stockton Formation (maximum thickness 1800 m) is the basal deposit consisting of thick beds of buff or cream colored conglomerate and sandstone, and red siltstone and sandstone. Throughout the exposed central portion of the Newark Basin, Kümmel recognized the Lockatong Formation (maximum thickness 1150 m) which is made up of gray and black siltstone arranged, as later shown by Van Houten (1969), in distinctive sedimentary cycles (Figure 4). The youngest formation Kümmel called the Brunswick. Throughout the Newark Basin, the lower Brunswick consists of sandstone and conglomerate and clusters of laterally persistent cycles of gray and black siltstone similar to the Lockatong Formation (Kümmel, 1897, 1898; McLaughlin, 1943; Van Houten, 1969). The upper Brunswick, on the other hand, is made up of three major extrusive basalt sheets which Darton (1890) called the Watchung Basalt, two major interbedded sedimentary units, and a thick overlying sedimentary unit. The latter sedimentary sequences have escaped even preliminary lithologic description.

Field work by this author during the past few years has shown that Kümmel's Brunswick For-

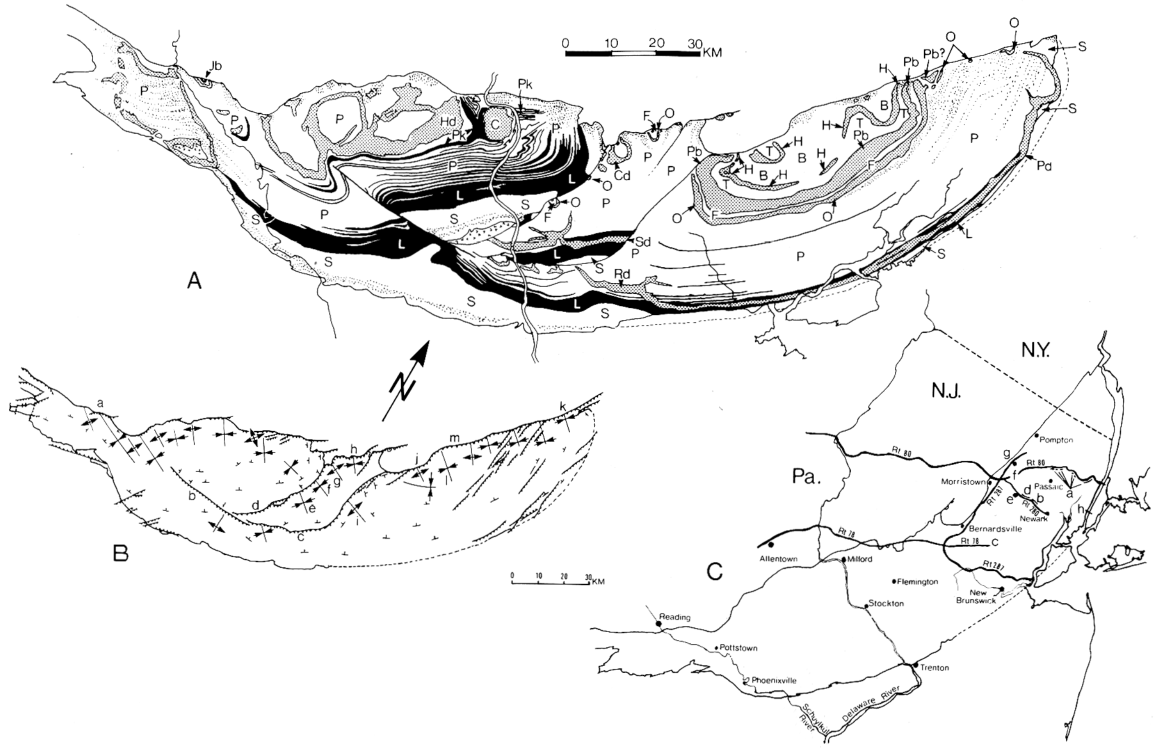

FIG. 2. The Newark Basin. A, geologic map showing distribution of formations, conglomerate facies (irregular stipple), and major clusters of detrital cycles in Passaic Formation (black lines). Abbreviations of formations and intrusive bodies as follows: B, Boonton Formation; C, Coffman Hill Diabase; Cd, Cushetunk Mountain Diabase; F, Feltville Formation; H, Hook Mountain Basalt; Hd, Haycock Mountain Diabase; Jb, Jacksonwald Basalt, L, Lockatong Formation; O, Orange Mountain Basalt; P. Passaic Formation; Pb, Preakness Basalt; Pd, Palisade Diabase; Pk, Perkasie Member of Passaic Formation; Rd, Rocky Hill Diabase; S, Stockton Formation; Sd, Sourland Mountain Diabase; T, Towaco Formation.

B, Structural diagram of Newark Basin (note — parts of basin margin not mapped as faults should be regarded as onlaps, faults with teeth on downthrown side): a, Jacksonwald Syncline; b, Chalfont Fault; c, Hopewell Fault; d, Flemington Fault; e, Sand Brook Syncline; f, Flemington Syncline; g, Cushetunk Mountain Anticline; h, New Germantown Syncline; i, Somerville Anticline; j, New Vernon Anticline; K, Ladentown Syncline; l, Watchung Syncline; m, Ramapo Fault.

C, Geographic map of Newark Basin showing locations of type sections of formations proposed in this paper: a, type section of Passaic Formation; b, type section of Orange Mountain Basalt; c, type section of Feltville Formation; d, type section of Preakness Basalt; e, type section of Towaco Formation in Roseland, New Jersey; f, type section of Hook Mountain Basalt in Pine Brook, New Jersey; g, type section of Boonton Formation in Boonton, New Jersey; h, Lincoln Tunnel, Weehawken, New Jersey.

Data for A, B, and C from original observation and Kümmel, 1897, 1898; Lewis and Kümmel, 1910-1912; Darton, 1890, 1902; Darton *et al.*, 1908; Glaeser, 1963; Sanders, 1962; Van Houten, 1969; McLaughlin, 1941, 1943, 1944, 1945, 1946a, 1946b; Bascom *et al.*, 1909a, 1909b; Bailey *et al.*, 1914; Willard *et al.*, 1959; Manspiezer; pers. comm.

mation consists of a heterogenous mix of major units of differing and distinctive lithology, each as distinct and perhaps originally as widespread as the Stockton or Lockatong; further, each "Watchung Basalt" and the interbedded and overlying sedimentary beds are lithologically distinct from the lower Brunswick. In addition, Cornet, McDonald, and Traverse (1973), Cornet and Traverse (1975), Cornet (1977), and Olsen and Galton (1977) have shown that much of the upper Brunswick is Early Jurassic rather than Late Triassic as had been assumed. It now seems clear that these Jurassic rocks are in many ways different from the Late Triassic lower Brunswick, Lockatong, or Stockton formations. For these reasons, I propose the terms Brunswick Formation (Kümmel, 1897) and Watchung Basalt (Darton, 1890) be dropped and their components subdivided to form seven new formations (Table 1) in parallel with Lehmann's (1959) widely used divisions of the Hartford Basin and Klein's (1962) divisions of the Fundy Group in accord with the American Code of Stratigraphic Nomenclature and the International Stratigraphic

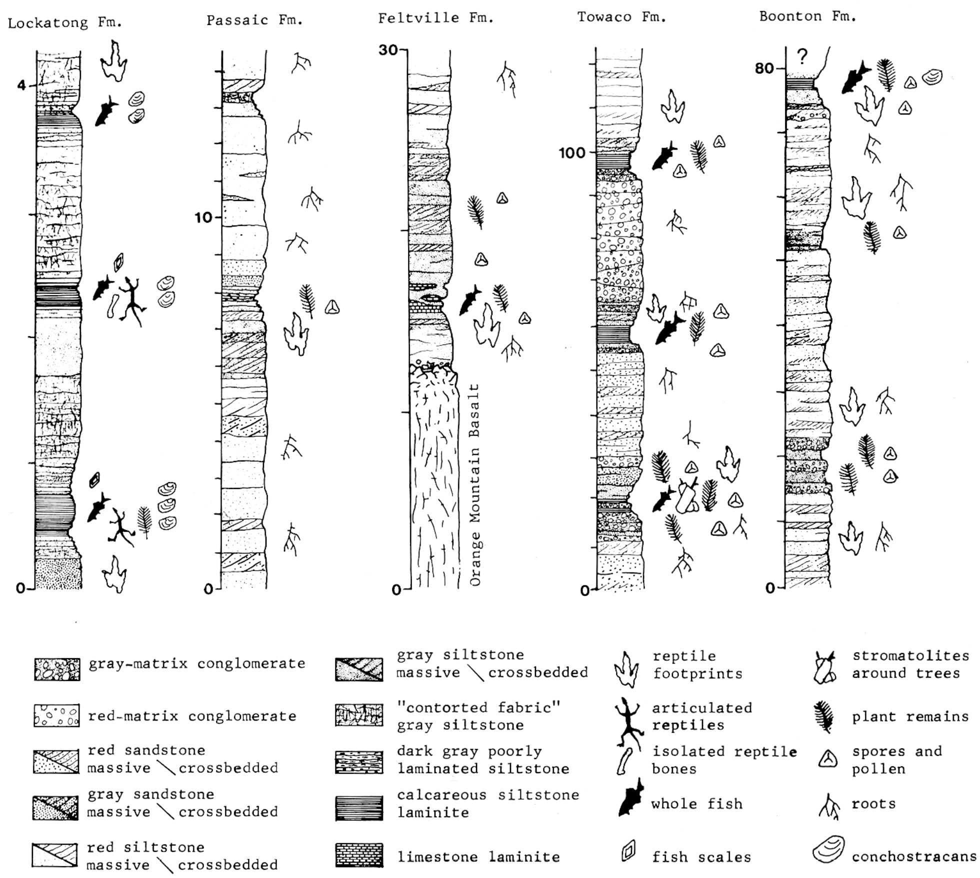

Fig. 3. Major types of sedimentary cycles of the formations of the Newark Basin. Note that the approximate center of the symbols for the major types of fossils is placed about where they occur in the section to the left. Note the change in scale (in meters) from section to section.

Lockatong Formation section measured at Kings Bluff, Weehawken, New Jersey, and represents three detrital cycles. The Passaic Formation section measured along Nishisakawick Creek and Little Nishisakawick Creek, northeast of Frenchtown, New Jersey; the two cycles shown represent the lower portion of McLaughlin's Graters Member (i.e., Member G) and are characteristic of most of the detrital cycles of the Passaic Formation. The upper cycle develops a dark gray siltstone a kilometer to the south. Feltville Formation section measured along East Branch of Middle Brook, Martinsville, New Jersey — there is only one such "cycle" in the Feltville Formation. Towaco Formation section measured along stream 2 km southwest of Oakland, New Jersey; three cycles are shown. Boonton Formation section is upper part of type section (see Figure 12); section not clearly cyclic.

Guide. In this way, nominal status is given to beds critical to the overall pattern of Newark Basin historical geology.

DESCRIPTIVE STRATIGRAPHY OF THE POST-LOCKATONG FORMATIONS

The Passaic Formation

The name Passaic Formation is proposed for the predominantly red siltstone, sandstone, and conglomerate which conformably overlie the Lockatong Formation and which underlie the Orange Mountain and Jacksonwald basalts. It is equivalent to the pre-basalt part of Kümmel's Brunswick Formation (Table 1). The type section (Figure 4) consists of intermittent exposures of red siltstone and sandstone along interstate Route 80 near Passaic, New Jersey (Figure 2 and Appendix).

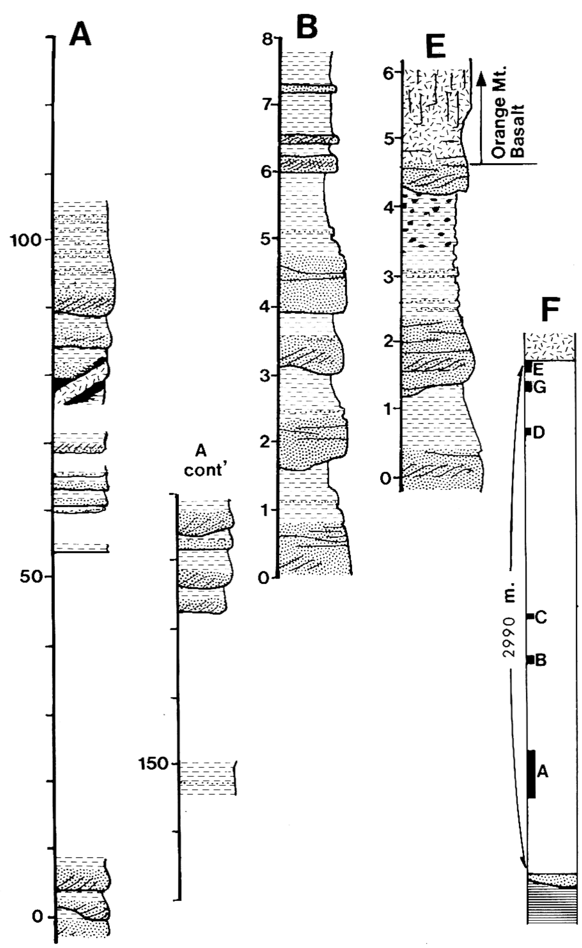

FIG. 4. A - E, type section of Passaic Formation (see Appendix for description); F, diagram showing positions of sections A - E in Passaic Formation.

As is the case for all Newark formations, the estimation of stratigraphic thicknesses in the Passaic Formation is hampered by the presence of a series of faults with variable amounts of dip-slip displacement cutting much of the Newark Basin. The exact distribution of these faults is poorly known and thus many trigonometrically computed thicknesses in the Passaic Formation are probably overestimations. This is especially true in the northern and southern portions of the Newark Basin. The field relationship of mapped gray siltstones in the central Newark Basin, however, shows that in broad areas these smaller faults are missing and the calculated stratigraphic thickness is probably correct (McLaughlin, 1943). Instead of a large number of small faults, the central Newark Basin is cut by several very large faults (Figure 2).

In spite of these mensuration problems, it is clear that the Passaic Formation is the thickest, coherent lithologic unit in the Newark Basin, reaching a maximum calculated stratigraphic thickness of over 6,000 m (Jacksonwald Syncline). The formation outcrops throughout the Newark Basin although its upper beds are preserved only in the Watchung Syncline (Figure 2), in the smaller synclines preserved along the eastern side of the Flemington Fault, and in the Jacksonwald Syncline. In all other areas, the upper Passaic Formation has been removed by post-Newark erosion.

While in most areas the Passaic Formation rests conformably on Lockatong Formation, in several areas on the western margin of the Newark Basin, the Passaic directly onlaps the step-faulted basement without any intervening Stockton or Lockatong. In these areas (see Figure 5), the thickness of upper Passaic Formation present below the Orange Mountain Basalt is comparatively slight. One area where these relationships can be clearly seen is near Cushetunk Mountain (Figure 5) in central New Jersey. In the New Germantown Syncline, the stratigraphic distance from the Palaeozoic basement to the Orange Mountain Basalt is about 800 m. Less than 30 km to the southwest, over 1,000 m of Passaic is

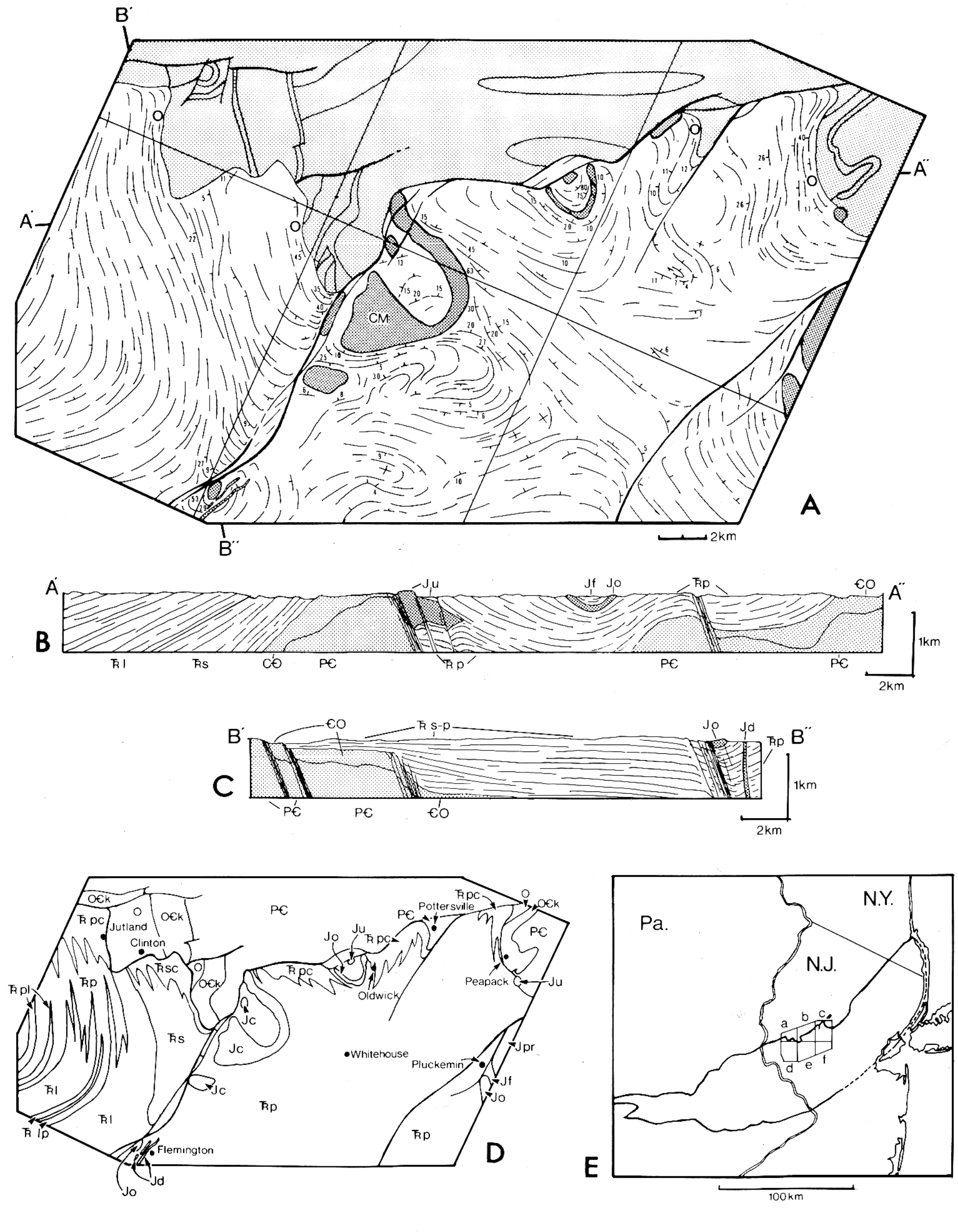

FIG. 5. Cushetunk Mountain area: A, map showing strike lines, degree of dip, major faults and onlaps (o) — diabase and basalt represented by dark gray shading while light gray shading represents Palaeozoic and PreCambrian basement rocks — CM is Cushetunk Mountain; B, cross section of area in A (above) along line A′-A″ — note vertical exaggeration; C, section of area in A (above) along B′-B″; D, geologic map of Cushetunk Mountain area (Oek, Cambrian and Ordovician sedimentary rocks of the Kittatinny carbonate terrane) O, allochthonous peltic and minor carbonate rocks; eO, combined Oek and O; Pe, Precambrian crystalline rocks; T lp, tongues of Triassic Passaic Formation lithology within main mass of Lockatong Formation; T pc, Triassic Passaic Formation, conglomeratic facies; T p, Triassic Passaic Formation; T pl, Triassic Passaic Formation, Lockatong-like clusters of detrital sedimentary cycles; T s, Triassic Stockton Formation; T sc, Triassic Stockton Formation, a conglomeratic facies identical to T pc; JF, Jurassic Feltville Formation; Jc, Jurassic Cushetunk Mountain

present above 2,000 m of Stockton plus Lockatong, and in the latter area the top of the Passaic Formation is not preserved. In less well exposed areas, or where the strike parallels the basin margin, such onlap and step-faulted relationships cannot be observed without geophysical techniques or analysis of well records (McLaughlin, 1943, 1944; Dunleavy, 1975).

Facies patterns of the Passaic Formation are a modified continuation of those of the Lockatong, and different from all younger Newark Basin deposits. Laterally persistent and periodically spaced clusters of gray and black siltstone cycles characterize both formations, the Lockatong being composed almost entirely of such repetitive units (see Figure 3). According to Van Houten (1962, 1964, 1965, 1969), the great majority of the Lockatong cycles fall into two broad classes which he terms chemical and detrital (Figure 3). The most laterally continuous are detrital and these generally occur in bundles. Each bundle is separated from the next (in vertical succession) by a series of chemical cycles; the distance from the center of one detrital cycle bundle to the next being about 110-125 m in the central Newark Basin (Van Houten, 1969). This figure decreases to the basin margins. Chemical cycles are characterized by the presence of abundant analcime and are for the most part restricted to the center of the basin, giving way in all directions to red clastics. The lateral edges of the Lockatong thus consist of bundles of detrital cycles separated by red siltstone and sandstone. It follows that the boundary between the Passaic Formation and the Lockatong can be operationally defined (both horizontally and vertically) as where the thicknesses of beds of red clastics dominate gray and black. It further follows that where gray and black detrital cycle clusters do not occur, as in Rockland County, New York, the Passaic Formation rests directly on the Stockton.

Bundles of detrital cycles occur through most of the thickness of the Passaic Formation, periodically spaced, as in the Lockatong. The great majority of these cyclic non-red units, however, are not as laterally continuous as those of at least the lower Lockatong, and generally the number of cycles involved in these clusters decrease in frequency through the Passaic Formation. For the lower and middle Passaic, McLaughlin (1933, 1943, 1945, 1946, 1948) has succeeded in mapping out the distribution of these non-red units over most of the central Newark Basin. A detailed stratigraphic framework has developed around these beds, each detrital cycle bundle being designated by a letter (A, B. C. . . . .). The extension of McLaughlin's units outside of the areas he mapped is a principle aim of ongoing research (Figure 2).

The highest of McLaughlin's mapped units (134 m above members L and M) join with other cycles to the southwest to form a large body of gray and black siltstone called the Perkasie Member (McLaughlin, 1946). Unlike the Lockatong Formation, however, the thickest section of the Perkasie Member is in the southwestern portion of the Newark Basin rather than near its geographic center. Due to repetition by major faults (Figure 2) and changes in strike along folds, the broader aspects of the three-dimensional relationships of most Passaic dark clastic units can be observed. Looking over the bulk of the Passaic Formation (Figure 2), there is no evidence that the rest of the detrital cycle clusters of the Passaic (i.e., other than lateral equivalents of the Lockatong Formation or Perkasie Member) represent the remnants of a large, now eroded, gray and black siltstone body as Glaeser (1963) has suggested.

There are major masses of red-matrix conglomerate at both the northern and southern ends of the Newark Basin (Figure 2). These grade nearly imperceptively into the red clastics of the Passaic Formation and are here considered facies of it. Other much smaller areas of conglomerate occur along the western border of the Newark Basin; these are especially prevalent where Passaic

Diabase; Jd, Jurassic diabase dikes; Jo, Jurassic Orange Mountain Basalt; Jpr, Jurassic Preakness Mountain Basalt; Ju, Jurassic basalt, undefined; E, geographic position and quadrangle maps of Cushetunk Mountain area (a, High Bridge Quadrangle; b, Califon Quadrangle; c, Gladstone Quadrangle; d, Pittstown Quadrangle; e, Flemington Quadrangle; f, Raritan Quadrangle).

Formation onlaps basement rocks (Figures 2 and 5).

A point of general applicability to perhaps most Newark Supergroup deposits and particularly relevant to Passaic Formation conglomerates is the lack of objective lithologic distinction between basal and border conglomerates. The small bodies of conglomerate present along the western border of the Newark Basin (so called fanglomerates) have traditionally been interpreted as genetically related to the presence of border faults and the presence of such conglomerates was often used as evidence for the faults themselves (Russell, 1922; Barrell, 1915; Sanders, 1963; Van Houten, 1969). It appears from relations presented in Figure 5 and geophysical evidence (Dunleavy, 1975) that many of these "border conglomerates" are in fact basal (see Sanders, 1974 and Faill, 1973). Conglomerates present in the basal Stockton Formation in the same area (west of Cushetunk Mountain, Figure 5) are lithologically indistinguishable from these Passaic conglomerates. The relationship of these conglomerates to the inferred syndepositional topography of the basin is not at all obvious and, thus, for the present, interpretive designations such as fanglomerate, basal conglomerate, and border conglomerate should probably be avoided.

Massive diabase intrusions are implaced through the upper Passaic Formation in the west central portions of the Newark Basin and in the lower Passaic Formation in the northern Newark Basin. These intrusions generally parallel the distribution of major bodies of gray and black siltstone: thus, the largest intrusions are broadly concordant (but locally discordant) with the Lockatong Formation (i.e., Palisades, Rocky Hill, and Sourland Mountain Sills) or the Perkasie Member of the Passaic (Haycock Mountain, Coffman Hill, and possibly Cushetunk Mountain diabases; see Figure 5). The general pattern seems to be for these intrusions to be implaced progressively higher in the Newark Basin section from east to west.

The Passaic Formation, like most Newark Supergroup deposits, is cut by a series of narrow, often nearly straight and vertical diabase dikes trending north and northeast. The mapping of the distribution of these intrusives is still very incomplete.

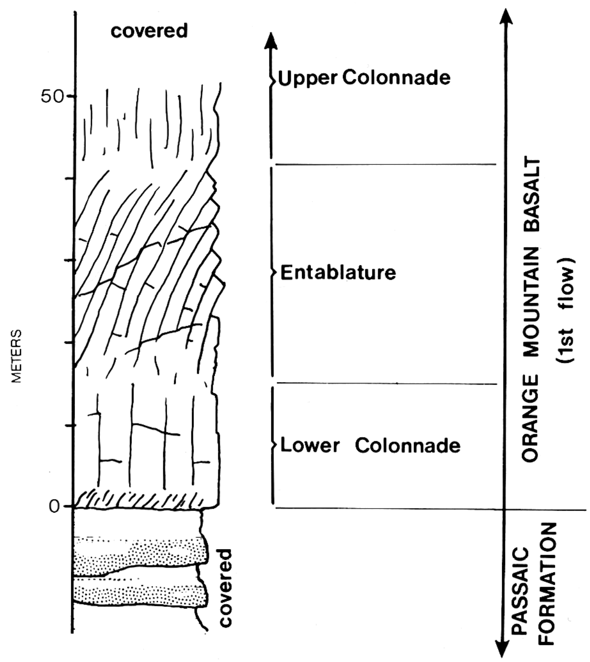

FIG. 6. Type section of the Orange Mountain Basalt; exposure along Interstate Route 280 in East Orange, New Jersey. In Passaic Formation, stipple represents red sandstone and plain area represents red sandstone.

Orange Mountain Basalt

Orange Mountain is the local name of the First Watchung Mountain in Essex County, New Jersey, long known for its spectacular exposures of columnar basalt (Cook, 1884); the name Orange Mountain is, therefore, suggested for these multiple (at least two), tholeiitic, basalt flows and interbedded volcanoclastic units above the Passaic Formation and below the Feltville Formation. The type section, exposing about 40% (50 m) of the formation's total thickness, is along Interstate Route 280 at its cut through Orange Mountain in East Orange, New Jersey (Figure 7). According to Puffer and Lechler (1980) the Orange Mountain Basalt belongs to the high-TiO_2 type of basalt of Weigand and Ragland (1970) and is chemically very similar to the Palisade Diabase.

The Orange Mountain Basalt is the oldest Newark Basin Formation thought to be wholly

Early Jurassic in age, and like other Jurassic beds in the Newark Basin, the main area in which the basalt is preserved is the Watchung Syncline (Figure 2). Smaller synclines preserve portions of the Orange Mountain in several other regions of the Newark Basin (Figure 2). In the New Germantown and Sand Brook synclines, the overlying Feltville Formation is preserved above the basalt; correlation by palynomorph assemblages and fossil fish (Cornet, 1977; Olsen, McCune, and Thomson, in press) demonstrate the identity of the Feltville Formation and by implication the underlying basalt. Between these two synclines is a newly identified very small outlier of basalt, preserved in what can be called the Flemington Syncline (Figure 5). Unfortunately, the remnant is so small that no sedimentary rocks are preserved above it. The simplest hypothesis identifies this remnant as an additional portion of the Orange Mountain Basalt. What has been termed the Jacksonwald Basalt (Wherry, 1910) outcrops in a syncline near the southern terminus of the Newark Basin (Figure 2) over 100 km southwest of the Watchung Syncline. Palynomorph assemblages recovered from the overlying sediments indicate correlation with the Feltville Formation (Cornet, 1977). There is no evidence to contradict the hypothesis that this outlier, too, represents the Orange Mountain Basalt. A possible remnant of Orange Mountain Basalt is present in the Ladentown Syncline in Rockland County, New York (Figure 2). Between this and the northern end of the Watchung Syncline is the Union Hill exposure of basalt. N. M. Ratcliff (pers. Comm.) has recently found exposures which show this unit to be extrusive, and, as such, it is most likely Orange Mountain Basalt. According to Geiger, Puffer, and Lechler (1980) and Geiger (personal communication), the Oldwick, Sand Brook, and Jacksonwald outliers are chemically identical to the Orange Mountain Basalt; while the Ladentown Outlier is chemically most similar to the Preakness Basalt (Second Watchung of Darton, 1890). Taken together, these remnants of Orange Mountain Basalt suggest that originally the basalt covered the almost entire Newark Basin, a minimum of over 7,000 km^2. This is comparable to the extent of the Holyoke Basin over the Hartford Basin and the North Mountain Basalt over the Fundy Basin.

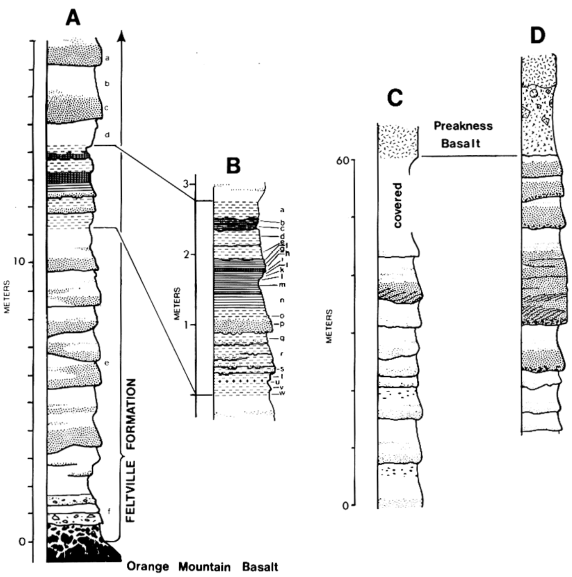

FIG. 7. Type section of the Feltville Formation and sections of the upper Feltville Formation.

A vand B, type section of the Feltville Formation; section exposed along ravine for Blue Brook about 1 km south of Lake Surprise in the Watchung Reservation. For key to individual units, see Appendix.

C and D, sections in the upper Feltville Formation. Dark stipple represents buff sandstone and feldspathic sandstone while the light stipple represents red sandstone and coarse siltstone. The light areas represent red siltstone and the black oblong dots, carbonate concretions. Section C is exposed along a tributary of East Branch, near Dock Watch Hollow, north of Martinsville, New Jersey. Section B is exposed in a cut in back of the Pleasant Valley Nursing Home in West Orange, New Jersey. C and D are 20 km from one another.

The Orange Mountain Basalt appears thickest in the Watchung Syncline, varying between 100 and 200 m. At least 130 and 120 m are present in the New Germantown and Sand Brook synclines, respectively, and greater than 100 m are present in the Jacksonwald Syncline. Existing exposures do not permit estimate of the thickness of the Flemington, or Union Hill.

Individual flows of the Orange Mountain Basalt (like other Newark Basin extrusives) are identified by recognition of the following criteria: glassy, dense, or discolored contacts at a flow boundary; thin volcanoclastic beds between flows; or a sequence of massive, columnar, and vesicular basalt identifying a single cooling unit as in a

Tomkeiff (1940) structural sequence. Using these criteria, a minimum of two flows are evident in most sections of the Orange Mountain Basalt in at least the Watchung and New Germantown synclines (Faust, 1975 and pers. obs.). The lower flow is exposed in the type section and consists of nearly a complete Tomkeiff sequence (Manspeizer, 1969). Other exposures of this flow are abundant. In most places the lower and upper flows are separated by a red volcanoclastic bed which is generally less than a meter thick (Bucher and Kerr, 1948; Johnson, 1957; Van Houten, 1969; Faust, 1975). In the New Germantown Syncline, however, the volcanoclastic bed is over 4 m thick and has numerous beds of red, purple, and gray, ripple-bedded and mudcracked siltstone. The upper flow is extensively pillowed and pahoehoe-like near the type section (Fenner, 1908; Van Houten, 1969) and locally at isolated spots throughout the Watchung Syncline. Elsewhere, however, the upper flow resembles the lower in having a large columnar entablature. Whether or not the two flows exposed at these outcrops represent single continuous sheets or smaller discontinuous units is as yet not known.

Feltville Formation

The sedimentary rocks above the Orange Mountain Basalt and below the Preakness Basalt are here termed the Feltville Formation. The Feltville consists of red siltstone and sandstone, buff, gray, and white feldspathic sandstone, and a thick, laterally continuous non-red unit containing a unique, frequently laminated limestone. This formation is named for the type exposure (Figures, 2, 7), in the old village of Feltville in the Watchung Reservation (Union County Park Commission), where about 15% of the total thickness of the Feltville Formation is exposed.

Like the underlying Orange Mountain Basalt, the Feltville Formation is preserved in the Watchung, New Germantown, Sand Brook, and possibly the Jacksonwald synclines (Figure 2). It averages about 170 m thick in the Watchung Syncline, apparently thickening to the southwest; at least 300 m are present in the Sand Brook Syncline, 600 m in the New Germantown Syncline, and at least 200 m in the Jacksonwald Syncline.

The Feltville Formation is distinguished from the underlying Passaic Formation and younger Jurassic formations of the Newark Basin by the presence of abundant beds of buff, gray, or white feldspathic sandstone interbedded with red siltstone in fining-upwards sequences (Figure 7); thus, much of the Feltville resembles the Stockton Formation. The lower half of this formation contains a black to white laminated limestone, calcarenite, and graded siltstone bed (0.4 - 3 m) containing abundant fossil fish. This lies between two beds (each 1 - 7 m) of gray, small to large-scale crossbedded siltstone and sandstone. As is true for the formation as a whole, these three beds are thickest in the New Germantown Syncline (> 14 m). The available evidence suggests that the Feltville Formation, like the Orange Mountain Basalt, originally occupied the whole area of the Newark Basin, and judging from the exposures in the Watchung Syncline and the other synclines in which the formation is exposed, the predeformational shape of the Feltville Formation was a wedge thickest along the western border of the basin.

Preakness Basalt

The name Preakness Basalt is proposed for the extrusive, tholeiitic basalt flows and interbedded volcanoclastic beds above the Feltville Formation and below the Towaco Formation. Preakness Mountain is the local name of the Second Watchung Mountain, a ridge of this basalt near Franklin Lakes, New Jersey. The type section includes about 30% of the formation and is located along Interstate Route 280 (Figure 8) about 2.25 km west of the Orange Mountain Basalt type section. This Preakness Basalt resembles the high-Fe_2O_3 basalt of Weigand and Ragland (1970) and resembles Walker's (1969) "second pulse" portion of the Palisades Diabase in trace element composition (Puffer and Lechler, 1980).

The Preakness Basalt is the thickest extrusive unit in the Newark Basin. The calculated thickness is 215 m at its northernmost outcrops at Pompton, New Jersey (Figure 9). Judging from outcrop width the formation thickens to the south to as much as 500 m near the type section. The

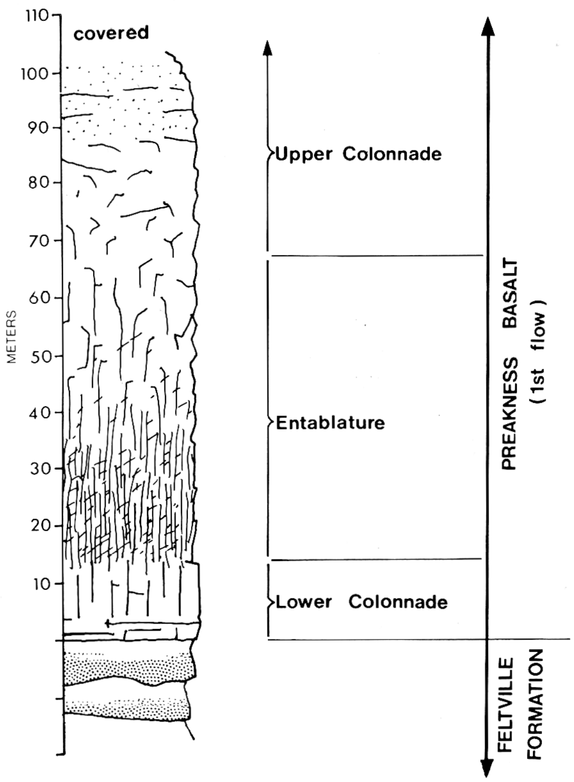

FIG. 8. Type section of the Preakness Basalt. Section located along Interstate Route 280, 2.25 km west of type section of the Orange Mountain Basalt. Symbols for Feltville Formation, as for Passaic Formation (Figure 6).

maximum figure is questionable since in the latter area the strike of the formation nearly parallels the trend of small faults cutting this region. That a figure of more than 300 m may be near the truth is suggested by the persistence of a large outcrop width around the southern curve of the Watchung Syncline. In contrast to the underlying units, the Preakness Basalt is not definitely preserved outside the Watchung Syncline. There are small masses of basalt at the northwestern edge of the New Germantown and Sand Brook synclines but the exposures are not good enough to tell whether these are beds lying stratigraphically above the Feltville or merely an upthrown fault slice of the Orange Mountain Basalt. However, on the basis of trace element geochemistry Geiger, Puffer, and Lechler (1980) have concluded that these small masses are Preakness Basalt. Likewise, according to the latter authors, the Ladentown flows are also Preakness Basalt.

At its base, the Preakness Basalt is much more variable than the Orange Mountain Basalt. Locally, there are thick (20 m, see Figure 9) sequences of multiple flows of highly vesicular basalt flows, possibly making up basalt forset beds (Manspiezer, pers. comm.) with intercalcated volcanoclastic beds; in other areas there are thick beds of angular, vesicular basalt breccia (aa). The latter tends to be very weathered and porous at the surface. In still other areas, the thick main basalt flow lies directly on unaltered (megasopically) sediments of the Feltville Formation.

At least two or perhaps three thick individual flows make up the bulk of the Preakness Basalt. The lowest flow is the thickest (about 100 m) and is exposed throughout the Watchung Syncline, usually showing a complete (although modified) Tomkeiff structural sequence. In most outcrops, the entabulature is coarse-grained and densely jointed, forming high, irregularly angular columns 0.1 m to 1.0 m in width, in marked contrast to those of the Orange Mountain Basalt. The first flow is separated from the second by a thin red siltstone, the distribution of which was mapped by Kümmel (1897) and Lewis (1907b)

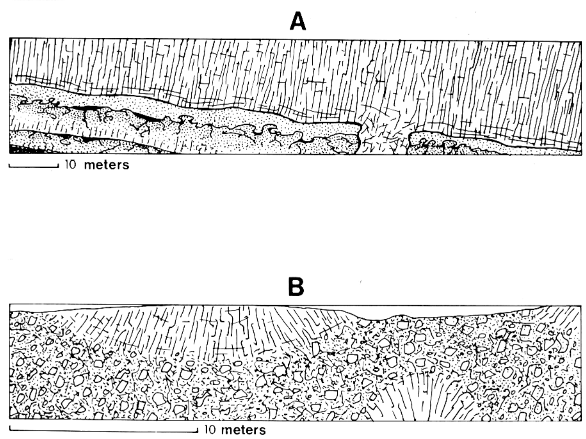

FIG. 9. Thin flow units at the base of the Preakness Basalt; A, thin pahoehoe flows and possible feeder dike along Interstate Route 78 in Pluckemin, New Jersey; B, possible aa flows exposed along the Passaic River at Little Falls, New Jersey (adapted from Darton, 1890).

in the southern portion of the Watchung Syncline (but see Faust, 1975). The extent of the second flow out of this area is not well known. Lewis (1908) states that all the basalt above the first flow belongs to a single flow 244 m thick, but in the northern part of the Watchung Syncline there is at least one other flow (Faust, 1975). This is separated from what I presume to be the second flow by a red and buff siltstone. This third flow is at least 60 m thick. Darton (1890) presented evidence of at least three flows in the Preakness Basalt at Pompton (Figure 10) where the formation is 215 m thick. Kümmel (1898) favors the hypothesis that the Pompton exposures represent a single flow repeated twice by faulting; that Darton's interpretation is more likely is shown by the extension of the upper two flows across Pine Lakes in Pompton in a direction exactly parallel to the strike of the overlying Towaco Formation but at an angle to the trend of the local faults (Figure 14). Finally, three flows appear present in the Ladentown outlier. More field work is needed to clarify the number and distribution of flows within the Preakness Mountain Basalt.

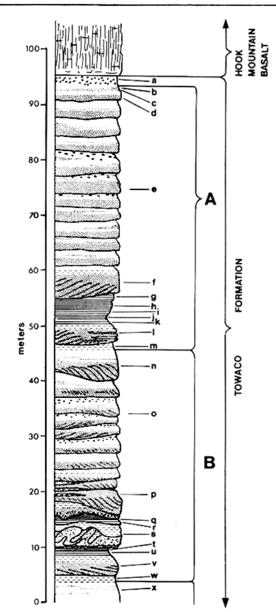

Fig. 10. Type section of the Towaco Formation in the Dinosaur Tract, Essex County Park Commission, Rosaland, New Jersey. For key to individual units see Appendix. A, upper cycle; B, lower cycle (not now exposed).

In several works, the Cushetunk Mountain Pluton has been tentatively referred to the Preakness Basalt (Second Watchung Basalt — see Sanders, 1962; Sanders, 1963). That this unit is definitely intrusive is shown by the following observations: 1, there is no vesicular portion; 2, the unit cuts across bedding; 3, there is a 20+ m thick metamorphic areole in the sediments around the body; 4, the unit is very coarse — in fact, a coarse granophyre pluton with chilled borders. The igneous mass which makes up Cushetunk Mountain is, therefore, an irregular intrusion injected into the upper Passaic Formation (see Puffer and Lechler, 1979).

The Towaco Formation

The name Towaco Formation is here applied to the red, gray, and black sedimentary rocks (and minor volcanoclastics) found below the Hook Mountain Basalt and above the Preakness Mountain Basalt in the Watchung Syncline. The type section is the Essex County Park Commission Dinosaur Tract (Roseland Quarry), Roseland, New Jersey, and is located about 12 km south of the village of Towaco, New Jersey, a classic reptile footprint locality (Lull, 1953), from which the formation takes its name. The type exposure consists of 60 m of the uppermost Towaco Formation making up 20% of the 340 m present in the area (Figure 12).

Laterally continuous, symmetrical sedimentary cycles characterize most of the Towaco Formation. These consist of a central black or gray microlaminated calcareous siltstone surrounded above and below by gray sandstone and siltstone beds arranged in fining-upwards cycles. Above and below these units are red clastics, also arranged in fining-upwards cycles. These symmetrical cycles are a mean of 35 m thick and bear a close resemblance to the East Berlin Formation (Hartford Basin) cycles described by Hubert, Reed, and Carey (1976). Towaco cycles are an order of magnitude thicker than Lockatong or Passaic Formation cycles and differ from the otherwise similar Feltville Formation non-red sequence in containing a predominantly clastic rather than carbonate laminated portion (Figure 3).

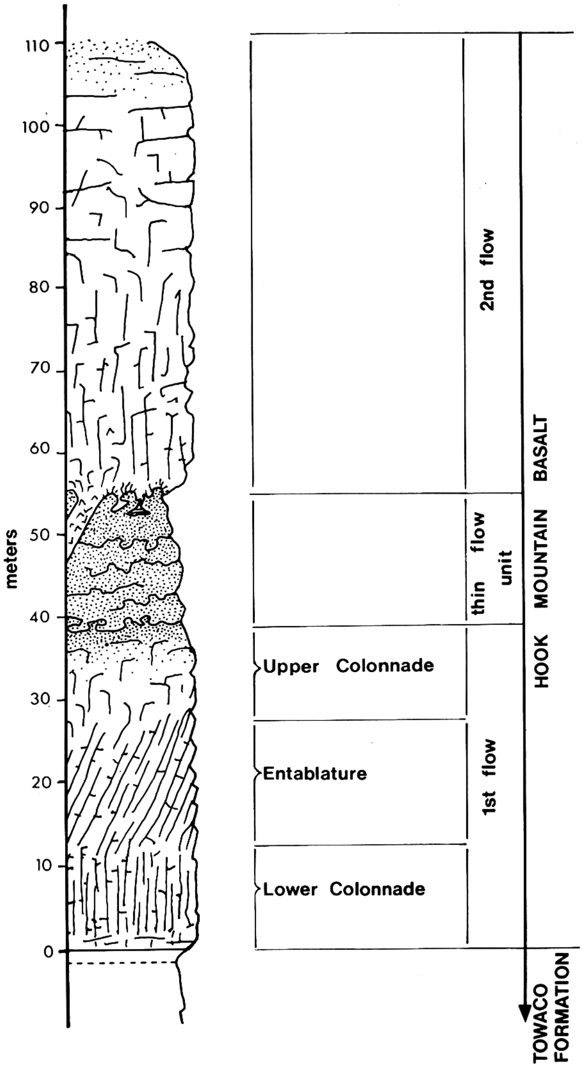

FIG. 11. Type section of the Hook Mountain Basalt. Note two major flow units and interbedded thin pahoehoe flows and possible feeder dike. Section exposed along Interstate Route 80 near Pine Brook, New Jersey.

The uppermost cycle is well exposed in the Roseland Quarry. Formerly another cycle was exposed in an adjacent area (Olsen, 1975), and yet another was located in a nearby well boring. In total, six successive cycles have been identified in the upper half of the Towaco Formation, and most of these have been traced throughout the Watchung Syncline.

There is a thin brown volcanoclastic unit at the top of the Towaco Formation. It is about 1 m thick and occurs at most exposures of the upper Towaco Formation from at least Pompton to Roseland. It is especially well exposed at the Towaco type exposure. Lewis (1908) described unweathered samples of this unit and noted that it consists of altered volcanic glass with inclusions of feldspar and augite and pseudomorphs after olivine in a matrix of brown radial natrolite. Small blocks of vesicular basalt are occasionally present and at Pompton very thin vesicular "flow breccias" are included in the unit (Faust, 1978).

The Hook Mountain Basalt

The uppermost extrusive volcanic unit in the Watchung Syncline is here formally designated the Hook Mountain Basalt (Baird and Take,

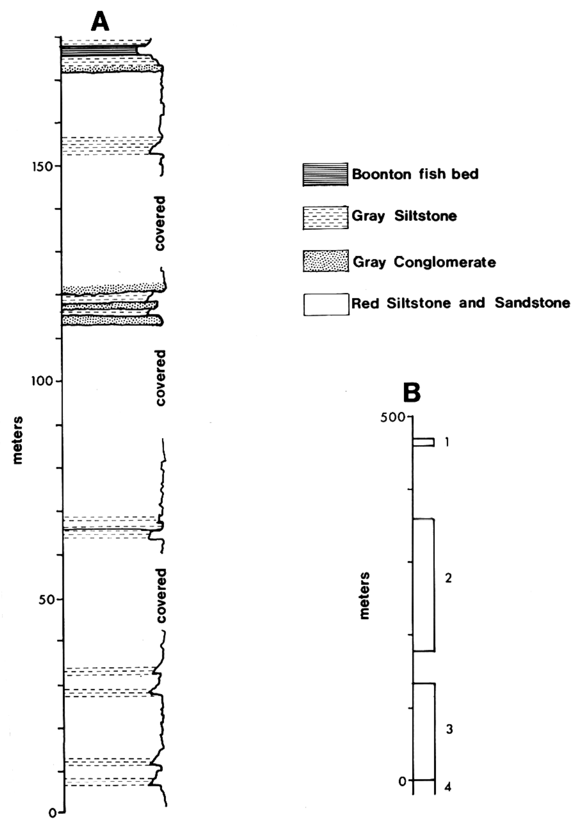

FIG. 12. Type section of the Boonton Formation; A, section exposed along Rockaway River in Boonton, New Jersey; B, composite section of entire preserved Boonton Formation — 1, red matrix conglomerate exposed at Chestnut Hill, Morristown, New Jersey, 2 beds making up the type section, 3, gray, black, brown and red siltstones exposed near Bernardsville, New Jersey, 4, Hook Mountain Basalt.

1959). This formation takes its name from the location of the type section (Figure 12) which cuts along Hook Mountain Road and Interstate Route 80 through the southern terminus of Hook Mountain near Pine Brook, New Jersey. About 80% of the total formation is exposed here. The Hook Mountain Basalt differs markedly in trace element composition from the older basalt formations of the Newark Basin with half as much K_2O and Sr, 20% less Rb, and with a much greater FeO/MgO ratio than the Orange Mountain Basalt (Puffer and Lechler, 1980).

The Hook Mountain Basalt is the thinnest of the three major extrusive formations of the Newark Basin; at its type section it is 110 m thick and it retains this thickness throughout the Watchung Syncline. There are gaps in the ridge made by this basalt between Hook Mountain and Riker Hill, and Riker Hill and Long Hill (see Figure 2). That the basalt extends subsurface across these gaps is shown by the bedrock topography as mapped by Nichols (1968) and aeromagnetic data (Henderson, et al., 1966). The maps of Lewis and Kümmel (1910-1912) and all maps since have omitted the Hook Mountain Basalt in the town of Bernardsville, New Jersey, and this is corrected here (Figure 2).

Two flows have been recognized through most of the Watchung Syncline. At the type section, the lower flow is 57 m thick and shows a complete Tomkeiff structural sequence (Figure 12), while the upper flow is 40 m thick but more massive, without clear columnar jointing. As is the case for the flows which make up the two older basalt formations of the Newark Basin, it is not definitely known whether the upper and lower flows of the Hook Mountain Basalt represent continuous sheets over the extent of the whole formation.

The Boonton Formation

Overlying the Hook Mountain Basalt are sedimentary rocks (Baird and Take, 1959) termed the Boonton and Whitehall beds of the Brunswick Formation. The formal name Boonton Formation is suggested for these beds, the type exposure (Figure 13) being along the Rockaway River near Boonton, New Jersey. The Boonton Formation is the youngest sedimentary unit in the Newark Basin and consists of at least 500 m of red, brown, gray, and black fine-to-coarse clastics and minor evaporitic beds.

The stratigraphically lowest beds in the Boonton Formation are well exposed near Bernardsville, New Jersey. Here the formation consists of blocky to finely bedded red, gray, brown, and black, often dolomitic, siltstone. Thin (1 - 4 m) beds riddled with "hopper casts" (pseudomorphs after gypsum, glauberite, and ?halite) are common in sequences of all colors. The different colors or textures of beds do not seem to be arranged in any obvious or consistent cyclic pattern and do not resemble other units in the Newark Basin. Stratigraphically above these beds is a sequence of well bedded red siltstones and sandstone beds (mean thickness 35 m) alternating with thinner beds of gray and gray-green siltstones (mean thickness 2 m). The longest continuous section of these beds is the type section (Figures 3 and 12). The uppermost beds at the type section include a fossil fish bearing calcareous gray siltstone laminite at least 1 m thick. This is the famous Boonton Fish Bed (Smith, 1900; Schaeffer and McDonald, 1978). Also in this section are gray and brown conglomerate units up to 0.5 m thick. Along the western edge of the Watchung Syncline the Boonton Formation contains thick sequences of red- and gray-matrix conglomerate and breccia. The relationship of these units to the finer portions of the formation is unclear.

NOTES ON THE STRUCTURAL GEOLOGY OF THE NEWARK BASIN

There are very few generalities which can be applied with confidence to Newark Basin structure. It is generally conceded, however, that: 1, Newark sediments rest with a profound unconformity on the basement rocks; 2, Newark rocks are overlain with an angular unconformity by post-Jurassic rocks; 3, most Newark beds dip to the northwest 10° - 20°; 4, there are a series of faults of large displacement which cut the Newark deposits into a series of major fault blocks; 5, there are at least some smaller faults; 6, beds of the west side of fault blocks tend to be folded into a series of anticlines and synclines with their axes perpendicular to the long axes of fault

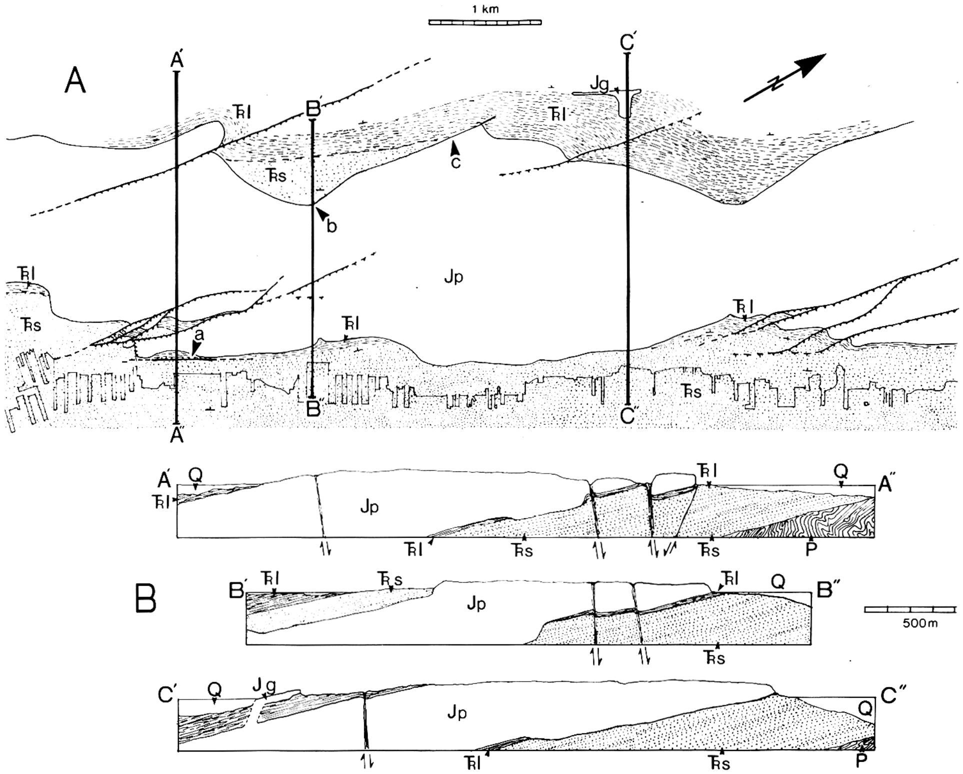

FIG. 13. Lincoln Tunnel area, Weehawken and Central Park Quadrangles. A, map of major lithologic units and structural features; B, sections through the Palisades Ridge. No vertical exaggeration. Abbreviations of lithologic units as follows: 1, Triassic Lockatong Formation; s, Triassic Stockton Formation; Jp, Jurassic Palisade Sill; Jg, Jurassic Granton Sill; P, metamorphic basement rocks of the New York City Group. a, b, and c refer to areas discussed in text. Faults with teeth on down dropped side.

blocks; and 7, beds on the east side of the same blocks tend not to be folded. The relationships of Newark Basin sediments to basin margins (i.e., faults or onlaps), the thicknesses of Newark strata, the number, distribution, and direction of smaller faults, the sense of motion of the major and minor faults (normal or oblique or strike-slip), and the physical relationships of joints to faults and folds have never been satisfactorily resolved, although research toward this goal is underway (Ratcliff, 1979). Obviously, all questions involving these features cannot be discussed in this paper, both because of lack of space and a lack of data. Enough observations have been made, however, to show some aspects of local structural style (Figures 5, 13, 14). There is no doubt, however, that Newark Basin structure is complex, and that further observation will change the results extracted even from the limited areas discussed here.

The Lincoln Tunnel area (Figure 13) of the Palisades Ridge forms part of the eastern edge of the Newark Basin and is cut by a series of putatively normal faults striking N 5-10° E, dipping vertically to 40° east, and with displacements of from 1 to 100 m (Fluur, 1941; Van Houten, 1969). Crush zones vary from a few centimeters to several meters (Fluur, 1941). There is also at least one major northwest-dipping normal fault on the east face of the Palisades (Kings Bluff) similar to those inferred to exist in the southern part of the Newark Basin by Sumner (1979) on the basis of geophysical data. This fault (a in Figure 14) was encountered during the construction of the north tube of the Lincoln Tunnel and is described in Thomas Fluur's unsurpassed work of the geology of the tunnel (Fluur, 1941). "The strike of the fault is approximately N 35° E and the dip 65° NW. Slikensides on the fault indicate that the movement had carried the block on the west side of the fault downward in respect to the east side with practically no horizontal component of movement. The fault is accompanied by numerous joints in both the shale and sandstone members adjacent. . . . The actual crush zone of the fault is only 0.5′ wide. . . . The movement was sufficient to bring up sandstones from a horizon much below that of the baked shales and in the movement the edges of the shale members were dragged upwards, so that close to the fault they show a maximum dip of 55° instead of the usual 15°" (p. 197). Finally, Fluur maps the presence of several minor faults striking S 80° E.

On the west slope of the Palisades Ridge, 1.5 km northwest of the Lincoln Tunnel, the sediment diabase contact is a plane tilting about 45° - 70° NW and striking an average of N 5° E for a distance of 3.25 km (Figure 13). This is one of the areas where the Palisade Diabase has more of a dike than sill appearance (Darton, 1892, 1902, 1908; Van Houten, 1969). For a distance of about 2 km, coarse cream- or buff-colored sandstones (apparently upper Stockton Formation) rest against the steeply dipping diabase wall. At a contact (b of Figure 14) described by Darton (1892, 1902) at the former West Shore Railroad Tunnel, the contact is welded at places and slightly undulatory. At an exposure 2 km north (c of Figure 14), however, there are well developed parting planes between the diabase and sandstone. In this area the sandstone, but not the diabase, is fractured and slikensided, the sense of motion being normal relative to the contact. The sandstone bedding is also dragged upwards at the contact. Just north of the latter outcrop (c of Figure 14), the Lockatong-Palisade-Sill contact is exposed. Lockatong Formation is exposed from there north to at least the George Washington Bridge. Although the situation is somewhat ambiguous, the contact and map relations are commensurate with a hypothesis of stepping up of the Palisade Sill in this region, so that the entire mass of upper Stockton and basal

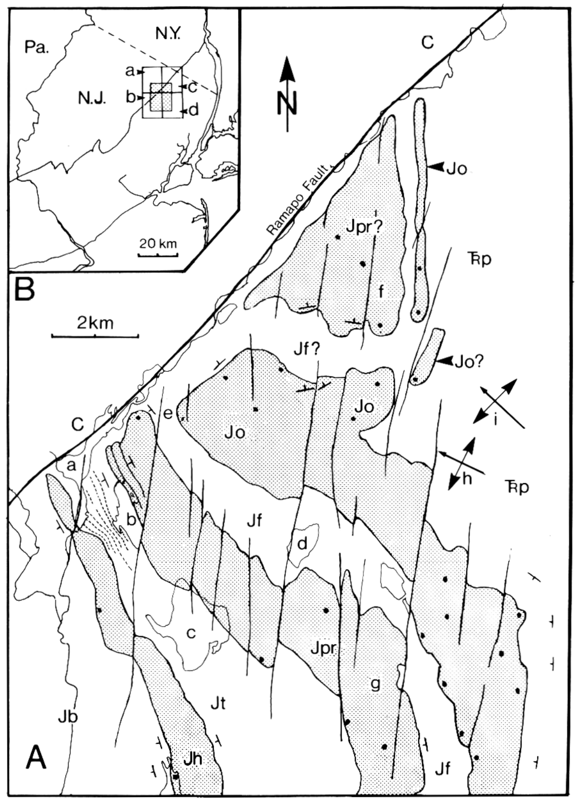

FIG. 14. Oakland Area, along Ramapo Fault, northwestern Newark Basin.

A, Preliminary geologic map: a, Pompton Lake; b, Pines Lake; c, Pequannock Reservoir; d, Franklin Lake; e, town of Oakland, New Jersey; f, Campgaw Mountain; g, Preakness Mountain; h, Oakland Anticline; i, Campgaw Syncline; C, crystalline rocks of the western highlands; p, Triassic Passaic Formation, conglomeratic facies; Jo, Jurassic Orange Mountain Basalt; Jf, Jurassic Feltville Formation; Jpr, Jurassic Preakness Mountain Basalt; Jt, Jurassic Towaco Formation; Jh, Jurassic Hook Mountain Basalt; Jb, Jurassic Boonton Formation. Note mapped distribution of laminite portions of Towaco cycles (dashed lines between Pines (a) and Pompton (b) Lakes) and mapped distribution of the three flows of the Preakness Mountain Basalt above and through Pines Lake (b). Also note that the distribution of major lithologic units is primarily based on maps of Darton, *et al.* (1908) and Lewis and Kümmel (1910-1912) with some major revision, especially in the areas around Pequannock Reservoir and Campgaw Mountain, where data from Henderson *et al.* (dots represent the latter's mapped aeromagnetic highs) and my own observations have been used.

B, Key, showing position of Oakland area (shaded) in Newark Basin and the relevant quadrangle sheets (topographic): a, Wanaque Quadrangle; b, Pompton Plains Quadrangle; c, Ramsey Quadrangle; d, Paterson Quadrangle.

Lockatong is lifted the thickness of the sill on the west side of the Palisade ridge, while on the east side the diabase rests above the stratigraphically equivalent portion of the Stockton and Lockatong (Figure 13).

The west edge of the northern part of the Newark Basin near Oakland, New Jersey (Figure 14) is like the east wall of the Hartford Basin in having served as a model for interpreting other Newark Supergroup Basins (Russell, 1892; Russell, 1922; Barrell, 1915; Sanders, 1963 — but see Faill, 1973). The nearly straight truncation of all Newark deposits and associated structures along a line striking N 45° E, local drag folding, and direct observation by borings (Ratcliff, 1979) indicate that a major fault, the Ramapo Fault, forms the northwestern edge of the Newark Basin, from at least Morristown, New Jersey to Theills, New York (60 km). Locally, at least, the fault dips 60° southeast (Ratcliff, 1979). At Morristown there is an offset to the east in the Ramapo Fault, and southwest of Bernardsville, New Jersey, the Ramapo Fault appears to join the braided northern continuation of the Hopewell Fault as suggested by Sanders (1962) and Manspiezer (pers. comm.). The northern portion of the Ramapo Fault is offset again at Theills, probably continuing northeast into Westchester County, New York (Ratcliff, 1973). As illustrated in the preceding discussion of the Cushetunk area and the structural map in Figure 2, such a long, linear fault as the Ramapo is, in truth, atypical for the western margin of the Newark Basin (as noted by Faill, 1973).

Newark Basin strata are warped into a series of anticlines and synclines along the Ramapo Fault, much as they are along the Flemington and Hopewell faults (Wheeler, 1939). These folds are oriented with their long axes more or less normal to the strike of the fault. These folds are, in turn, cut by a series of smaller faults (most of which probably have a large dip-slip component) downdropping to the east and striking, like those of the Lincoln Tunnel region (Figure 13) N 5° - 10° E (Figure 14). While apparent map offsets due to these faults are most obvious close to the Ramapo Fault (Figure 2), some of this series make it as far south as Newark, New Jersey; in fact, both the type section of the Orange Mountain and Preakness Mountain Basalts are cut by a series of faults. It is not clear if any of these faults completely cross the basin, however. Like the folds along the basin edge, these faults terminate to the north along the Ramapo Fault.

Along the northwest border of the Newark Basin, in the Cushetunk Mountain area (previously mentioned, Figure 5), Newark strata onlap onto a step-faulted basement. To the west of Bernardsville, the border of the Newark Basin consists of a series of faults trending N 35° - 50° E and N 5° -10° E, the latter being truncated by the former, and a series of onlaps of Stockton through Passaic Formation on basement. As is evident from Figure 5, the pre-Newark floor must have been some 5,000 m deeper near Clinton than at Potterstown during the deposition of the Orange Mountain Basalt. These rather complex relationships are best explained by a hypothesis of "piano-key" fault blocks bound by faults with a major normal component striking N 35° -50° E. During deposition of the younger Newark Basin beds, these blocks formed ramps which dipped southwest into the basin along their long axes at about 13° and thus resemble the right echelon relay faults and ramps described by Kelly (1979) for the Rio Grande Rift. Near Jutland, New Jersey, basal Passaic Formation apparently laps over one of the N 40° E faults, presumably indicating that the fault ceased movement prior to the deposition of these Passaic beds, an interpretation implied by McLaughlin (1946).

Thus, on the basis of these three areas it is possible to conclude that Newark Basin strata are cut by at least three sets of faults, most probably normal; one set striking N 30° - 50° E, dipping southeast on the west edge of the basin; another, as yet poorly known set with the same strike as the latter but dipping northwest, dropping beds down to the northwest; and a third set striking N 5° - 10° E. The southeast dipping northeast striking faults truncate the major folds in Newark strata as well as the other faults, while the more northerly striking faults cut but do not terminate folds and are responsible for the difficulty in making reliable thickness estimates of Newark Basin beds. There are definitely more faults present and of more varied nature than mentioned above. Kümmel (1897) and Darton (1890) show the presence of several reverse faults and small thrusts, and my own observations show additional faults parallel to bedding often with substantial crush zones. Work is now being carried out, however, on these topics (Ratcliff, pers. comm.).

Sanders (1962, 1963, 1974) has proposed that many of the faults described here as dip-slip are actually strike-slip. It is indeed true that there are abundant sets of non-vertical slikensides at virtually all exposures of Newark Basin beds near major faults; however, as noted by Faill (1973), the evidence from drag folding along major faults probably indicates major movement was dip-slip. Reasons for postulating many kilometers of strike-slip motion along major faults seems unconvincing to this author. Nonetheless, horizontal and oblique slikensides attest to some horizontal movement during the faults' history — perhaps at a relatively late stage.

Relating these structural features, outlined here for small areas of the northern part of the Newark Basin, to the southern portions of the basin is not yet possible, though it is a subject of ongoing field work. Despite recent progress, regional synthesis of Newark Supergroup structure is still years in the future.

PALEONTOLOGY AND BIOSTRATIGRAPHY

Despite numerous statements to the contrary, fossils of many kinds are abundant in the sedimentary rocks of the Newark Basin and in the Newark Supergroup as a whole (Thomson, 1979). The supposedly nearly barren Passaic Formation has produced literally thousands of reptile footprints (Baird, 1957), as have portions of the Towaco Formation (Olsen, 1975). Fossil fish with superb morphological details have proved abundant in all three Jurassic sedimentary formations (Olsen, McCune, and Thomson, in press; Thomson, 1979). Megafossil plant remains have also proved to be locally abundant and well preserved (Bock, 1969; Cornet, 1977) and fossil pollen and spore assemblages have been recovered from all major sedimentary units (Cornet, 1977). Even what are usually regarded as some of the rarest of all vertebrate fossils — articulated small reptile skeletons — are locally abundant (Olsen and Colbert, MS; Colbert and Olsen, MS). The distribution of characteristic fossils in the formations described in this paper are given in Figure 3 and the Appendix, Table 2. Obviously, such fossil remains are the grist of biostratigraphic correlation and paleobiological studies. Work has just begun on these areas, but it is already clear that the Newark Basin section

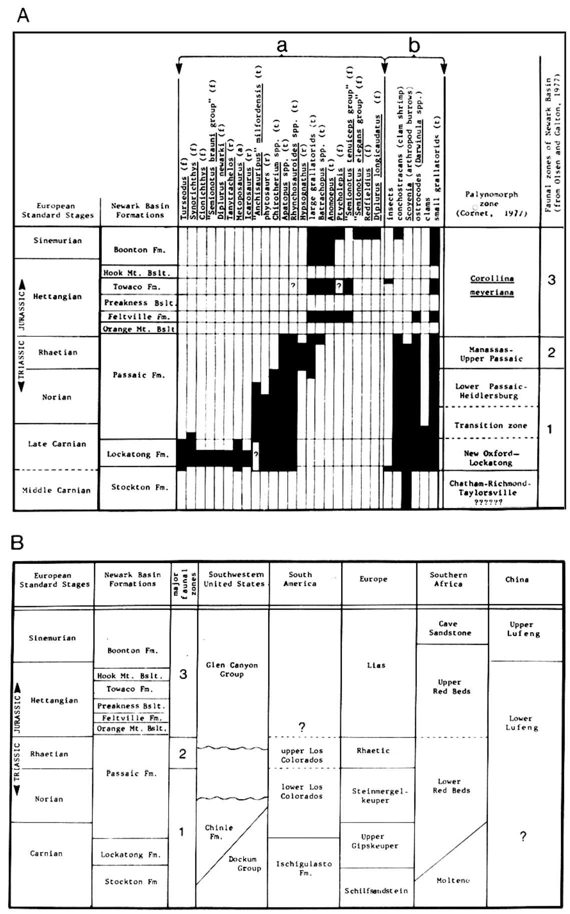

FIG. 15. A, Distribution of most abundant vertebrate and invertebrate fossils in the Newark Basin: a, taxa thought to be biostatigraphically important; b, taxa thought to be of little or biostratigraphic value. Letters in parentheses (f), (r), (a), (f) indicate nature of fossils: (a) amphibian; (r) reptile; (f) fish; (f) reptile footprints.

B, Correlation of the formations of the Newark Basin with other early Mesozoic sequences.

Data for A and B from Cornet (1977), Olsen and Galton (1977), Olsen, McCune and Thomson (in press), Olsen, Barid, and Salvia (MS), and Olsen and Colbert (MS).

will serve as a reference standard for comparison with other early Mesozoic areas.

The basic biostratigraphic framework for Newark Basin deposits has been outlined by Olsen and Galton (1977) and Cornet (1977) and the details of this correlation will be given elsewhere (Olsen, McCune, and Thomson, in press; Olsen, Baird, and Salvia, MS; and Colbert and Olsen, MS). At this time it is necessary to present the distribution of taxa within the Passaic through Boonton formations and tie these in with the regional correlation (Figure 15).

For regional correlation, relatively strong emphasis has been placed on the distribution of palynomorph taxa (Cornet, 1977, and pers. comm.). This reliance has been especially strong for correlation between the upper Newark and the European Early Jurassic (see Figure 15). Tetrapod data, both in the form of skeletal remains and footprints, parallel the palynomorph data, and have been essential in correlating regions from which floral data is not available (such as the upper Stormberg — J. M. Anderson, pers. comm.). For fine internal correlation of the Early Jurassic portions of the Newark, however, the biostratigraphic subdivisions based on pollen and spores have proved too broad (Cornet, 1977). In these areas, fossil fish have provided a means of correlation (Olsen, McCune, and Thomson, in press).

The broad aspects of this biostratigraphic correlation are in agreement with most geophysical data, significantly the paleomagnetic work of McIntosh (1976) and Reeve and Helsley (1972) on the Newark Basin section and the Chinle Formation (southwestern United States), as well as with the paleomagnetic work of DeBoer (1968). In addition, radiometric dates available for Newark Basin basalts are in agreement with a Jurassic age for these units (Armstrong and Besancon, 1970; Dallmeyer, 1975; Sutter and Smith, 1979; W. D. Masterson and K. K. Turekian, pers. comm.). It must be noted, however, that the geophysical techniques used to date may be too inconsistent for the data to be used in fine scale correlation among the various individual formations of the Newark Supergroup.

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APPENDIX

Type Section of the Passaic Formation

Thickness (m)	Description
Section A	Base of section A is 427 m above and 3.4 km west of last exposures of Lockatong along Rt. 80 (all sections measured from top down).
1.2	red blocky siltstone
1.8	red massive feldspathic sandstone
.6	red siltstone
1.2	red massive feldspathic sandstone, fining-upwards
3.1	red blocky siltstone
3.0	red fine feldspathic sandstone, fining-upwards
1.5	red blocky siltstone
1.8	red cross-bedded feldspathic sandstone, fining-upwards
26.0	covered
4.6	red siltstone
41.0	covered
6.1	red fissile siltstone
4.6	red interbedded sandstone and siltstone
3.0	red siltstone
0.6	red feldspathic sandstone, fining-upwards
0.3	red blocky siltstone
1.8	red feldspathic sandstone, white near diabase, fining upwards
1.5	diabase dike
+3	red blocky siltstone, black near diabase
5.0	covered

Thickness (m)	Description
.9	red cross-bedded sandstone and siltstone, fining-upwards
.8	red planer, thin-bedded sandstone
4.0	covered
4.6	red interbedded siltstone and sandstone
2.0	covered
1.2	red burrowed sandstone and siltstone
48.0	covered
.8	red blocky siltstone
1.5	red feldspathic sandstone, strongly downcutting, fining-upwards
3.4	red blocky siltstone
.7	red feldspathic sandstone, fining-upwards, deeply downcutting
.3	red blocky siltstone, covered in places
+1	red fine feldspathic sandstone
Section B	Base of exposure 488 m above and 3.4 km west of top of section A, along Rt. 80 (section measured from top down).
.61	red fissile siltstone
.15	yellow-orange planer-bedded coarse siltstone
.91	red blocky siltstone
.15	yellow-orange cross-bedded base, planer-bedded top, fine sandstone
.20	red blocky siltstone
.30	yellow-orange cross-bedded base, planer-bedded top, fine sandstone
.90	red fissile siltstone
.93	red blocky siltstone, fining-upwards
.32	red fissile siltstone
.60	red siltstone
.76	red fissile siltstone
.60	red coarse feldspathic sandstone, fining-upwards
.30	red blocky siltstone
1.32	red very fine sandstone, fining-upwards
+1.52	red blocky siltstone
Section C	Base of exposure 244 m above and 1.8 km west of top of section B, along Rt. 80 (sections measured from top down).
1.5	red, very irregular, trough cross-bedded sandstone grading upwards into siltstones, laminated carbonate-rich oblong chips and concentric accretions at base
1.5	same as above
Section D	Base of exposure 1320 m above and 6.9 km west of top of section C (section measured from top down).
3.0	red massive, cross-bedded sandstone
Section E	Base of exposure 554 m above and 2.9 km west of top of section D (section measured from top down).
+10.0	massive basalt — base of Orange Mountain Basalt
.9	brown massive sandstone welded to basalt
1.8	red siltstone with numerous small carbonate nodules
.93	red siltstone
1.5	red sandstone, fining-upwards

Type section of the Feltville Formation and key to figure 7. Section exposed along Blue Brook about 1 km southwest of the dam for Lake Surprise in Watchung Reservation, Union County, New Jersey (sections measured from top down).

Unit letter in Figure 7	Thickness (m)	Description
Section A of Figure 7		
a	+1	buff to pink, cross and planer-bedded feldspathic sandstone with interbeds of red siltstone upward grading into
b	+1	red siltstone in thin beds, upper contact sharp
c	+1	same as unit a
d	+1	same as unit b
e	9	< 1 meter thick beds of buff and red sandstone, grading upwards into red blocky siltstone
f	1.5	beds of red siltstone and sandstone with varying amounts of basalt breccia
Section B of Figure 7		
a	.5	greenish-red, slightly micaceous with small scale ripple-bedded siltstone
b	.05	gray, aphanitic, calcareous siltstone
c	.08	same as above with a thin unit of red siltstone between it and unit b
d	.25	red and green, fine bedded siltstone
e	.20	reddish green fine bedded siltstone
f	.05	gray indistinctly bedded very calcareous siltstone
g	.02	gray well bedded calcareous siltstone
h	.08	gray well bedded limestone laminae alternating with siltstone to form 5 mm thick couplets. *Semionotus* common
i	.06	gray aphanitic limestone
j	.05	gray graded beds (1010 mm) of calcareous siltstone
k	.05	similar to unit h, but couplets 2-3 mm. *Semionotus* common
l	.06	similar to above but more silty
m	.08	gray laminated siltstone with limestone laminae present occasionally
n	.46	mottled gray and red clayey siltstone with thin fossil roots. Palyniferous (W. B. Cornet, pers. comm.)
o	.03	gray coarse siltstone
p	.18	gray small scale cross-bedded coarse siltstone with numerous natural casts of reptile footprints on lower contact
q	.18	gray ripple-bedded fine siltstone with numerous reptile footprints
r	.31	gray ripple-bedded coarse siltstone grading into unit q. Reptile footprints common.
s	.08	same as p
t	.14	gray and reddish siltstone with numerous reptile footprints
u	.44	red and gray claystone
v	.05	gray and red siltstone with large dinosaur footprints
w	.13	gray and red siltstone with numerous reptile footprints

Type Section of the Towaco Formation
(measured from top down)
(see Figure 11)

Basal Hook Mountain Basalt and cycle A of Towaco Formation exposed in the "Dinosaur Tract" of the Essex County Park Commission adjacent to the "Nob Hill" condominium project, where cycle B and the upper part of cycle C were exposed prior to 1977 (Olsen, 1975). All these exposures were part of the Roseland Quarry, Roseland, New Jersey.

Unit letter from Figure 16	Thickness	Description
Hook Mountain Basalt, 1st flow	35.0	Tholeiitic Basalt. Massive at base, columnar jointed in middle, vesicular at top.
Towaco Formation Volcanoclastic bed		
a	.9	Brown, badly weathered palagonitic unit consisting of shards of altered glass in a matrix of brown ?radial natrolite when fresh.
Upper Cycle (A)		
b	.5	Light gray and lavender siltstone, locally laminated with small scale cross-bedding. May contain volcanoclastic component.
c	1.2	Dark lavender and maroon siltstone with small scale crossbedding. Small orange crystals (weathered) along fracture planes.
d	1.8	Deep red, hard siltstone grading into units above and below. Contains one fining-upwards cycle with reptile footprints common.
e	29.3	10 red fining-upwards cycles, each a mean of 2.9 m thick and composed of thick beds of red sandstone or coarse siltstone with prominent slip-off surfaces grading up into beds of ripple-bedded siltstone and blocky siltstone. Lowest cycle contains buff intraformational breccia with coprolites, reptile bone fragments, and fish scales. Lower cycles contain numerous calcareous lenticular concretions most common in coarse parts of cycles. Fine parts of middle cycles contain numerous small dolomitic concretions and deep mud cracks. Reptile footprints common in lower and upper cycles, as are root casts.
f	3.4	Gray and buff fining-upwards cycles consisting of a lower, cross-bedded sandstone grading up into lavender and gray siltstone. Reptile footprints and carbonized plants common.
g	1.1	Gray-green fine siltstone massive and indistinctly bedded. Small bits of carbonized stems and leafy twigs common. Palyniferous (Cornet, 1977).
h	.6	Dark to light gray, very fine and fine siltstone with massive to fine bedding and local load casts and ?gypsum crystal impressions. Good plant fragments including several conifer species, *Semionotus* scales and bones, and a single beetle elytron.
i	.4	Black, slickensided very fine siltstone with common chert nodules with a globular fabric.
j	.2	Black laminate. Black carbonaceous siltstone and white carbonate couplets .42 mm thick. Upper part of unit has several 5 mm thick graded, black siltstone layers. Grades into unit i.
k	.3	Light gray clayey siltstone, soft with black laminae becoming common upwards. Grades into unit j.
l	2.5	Gray fining-upward cycle composed of a lower cross-bedded sandstone containing numerous tree limbs, branches and roots grading upwards into a fine, well-bedded siltstone, locally ripple-bedded with numerous reptile footprints. Uppermost portion contains gray-green massive siltstone.
m	.9	Gray-buff, well bedded siltstone with dinosaur footprints and plant roots preserved both as carbonized impressions and natural casts.
Cycle B		
n	4.2	Red, thick fining-upward cycle. Lower part consists of thick beds of red sandstone with slip-off surfaces, local intraformational conglomerates and natural casts of large tree limbs or roots and a possible large reptile jaw. Middle part composed of 5 cm $\pm$ fine graded beds with very rare bone fragments and ?dinosaur teeth and exceptionally good reptile footprints. Plant fragments common and preserved as impressions or natural casts. Upper part is fine siltstone and plant remains present either as natural casts or carbonized compressions surrounded by gray-green halos. Grades upward into unit m.

Unit letter from Figure 16	Thickness	Description
All but the top of the following are no longer exposed.		
o	16.8	6, red fining-upwards cycles. Each cycle similar to unit n but a mean thickness of less than 1 meter. Middle 3 cycles contain numerous round dolomitic concretions and deep mudcracks in the fine portions. Reptile fooprints common; plant remains (twigs and roots) present as impressions and natural casts.
p	5.2	2 or 3 gray fining-upwards cycles pinching out to the south where only one remains. Lower part of cycle consists of gray and buff cross-bedded sandstone grading upward into fine gray-blue or gray-green siltstone. Uppermost cycle composed of gray sandstones and red siltstones. Plant remains common as carbonized compressions, fine units palyniferous and reptile footprints common.
q	.8	Basal portion is a laminate composed of laminae of dark organic-rich siltstone alternating with light carbonate laminae forming couplets 0.4 mm thick. Upper part of laminate has 5 mm black graded beds. Upper part of unit consists of beds of graded sandstones and siltstones with minor intraformational conglomerate made up of the laminite. *Semionotus* abundantly preserved as articulated compressions in laminite and in three dimensions in the sandstones. Carbonized plant compressions common.
r	.2	Black indistinctly-bedded siltstone. Gradational with unit s.
s	4.9	Olive massive slurried and convoluted bedded coarse poorly sorted siltstones grading upwards into poorly bedded gray-blue siltstones with numerous clasts of unit t throughout. Some recumbent folds over a meter between limbs.
t	.5	Black laminite very similar to laminite of unit q but without *Semionotus.*
u	.6	Light gray or buff clayey siltstone grading into units t and v. Black laminae common upward.
v	3.0	Gray fining-upwards cycle composed of basal coarse, cross-bedded siltstone grading up into fine siltstone. Carbonized fragments of plants present.
w	1.0	Gray small-scale cross-bedded siltstone, grades downward into unit x.
Cycle C		
X	4.3	Red small-scale cross-bedded siltstone.

Table 6

Type section of the Boonton Formation

Top of section exposed just east of the dam for the Jersey City Reservoir in Boonton, New Jersey. Section measured from top down (see Figure 20).

Thickness (m)	Description
+1	Gray coarse to fine siltstone and sandstone (now covered)
+1	Gray laminite composed of laminae of gray siltstone alternating with laminae of carbonate forming couplets of a mean of 2.5 mm. Unit also contains coarse to fine graded siltstones 1 mm to 2.5 cm thick. Fossil fish of 4 genera (see Figure 15) present along with numerous carbonized plant compressions and conchostracans. This is the famous Boonton Fish Bed (unit now covered).
.5	Gray clayey siltstone with common carbonized plant compressions (mostly conifers). Unit palyniferous (Cornet, 1977).
1.2	Gray fining-upwards cycle made up of coarse to fine cross-bedded sandstone grading up into small-scale cross-bedded siltstone. Reptile footprints common.
15.7	Red sandstone and siltstone in indistinct fining-upwards cycles. Small-scale cross-bedding common. Dolomitic concretions and reptile footprints present.
3.4	Gray coarse siltstone grading up into fine gray siltstone. Carbonized plant compressions present. Unit palyniferous.
+5	Red sandstone and siltstone in indistinct fining-upwards cycles. Small-scale cross-bedding common. Dolomitic concretions present.
ca.20	covered

Thickness (m)	Description
+5	Red sandstone and siltstone in indistinct fining-upwards cycles. Small-scale cross-bedding common (mostly covered).
1.1	Gray fine sandstone to fine conglomerate. Cross-bedded (tongue of Morristown facies).
2.6	Gray clayey siltstone with carbonized plant fragments.
1.4	Gray fine sandstone to conglomerate, cross-bedded with fine siltstone interbeds and carbonized plant fragments (tongue of Morristown facies).
1.6	Gray clayey siltstone with groove casts. Carbonized plant remains present.
+1.5	Gray sandstone and conglomerate, cross-bedded (tongue of Morristown facies).
ca.30	covered
+17.0	Red sandstone and siltstone in indistinct fining-upwards cycles. Small-scale cross-bedding common. Dolomitic concretions and reptile footprints present.
.9	Red and gray fine siltstone.
.9	Gray fine siltstone.
1.4	Gray fine sandstone and coarse siltstone: small-scale cross-bedding and carbonized plant fragments present.
+.9	Gray fine siltstone with carbonized plant fragments.
ca.20	covered
+7.9	Red sandstone and siltstone in indistinct fining-upwards cycles. Small-scale cross-bedding common. Dolomitic concretions and reptile footprints present.
1.5	Gray fine siltstone with carbonized plant fragments.
3.1	Red siltstone with dolomitic concretions and small-scale cross-bedding.
ca.1	Gray fine siltstone (poorly exposed).
13.8	Red sandstone and siltstone in indistinct fining-upwards cycles. Small-scale cross-bedding common. Dolomitic concretions present.
ca.1	Gray fine siltstone (poorly exposed).
1.5	Red siltstone with small-scale cross-bedding.
.8	Gray coarsening upwards siltstone.
6.1	Red sandstone and siltstone in indistinct fining-upwards cycles. Small-scale cross-bedding and dolomitic concretions common.